Coupled Ecological Model - Water Velocity/Water Quality and Adult Chinook Behavior at the Locks

Frederick A. Goetz

U.S. Army Corps of Engineers

Seattle District

with

J. Nestler ERDC

Andy Goodwin, USACE

Larry Weber, University of Iowa

Adult Chinook Passage

Problem: Adult salmon can hold at the Locks for over 50 days in a small localized area immediately upstream of the Locks with unknown effect on reproductive success.

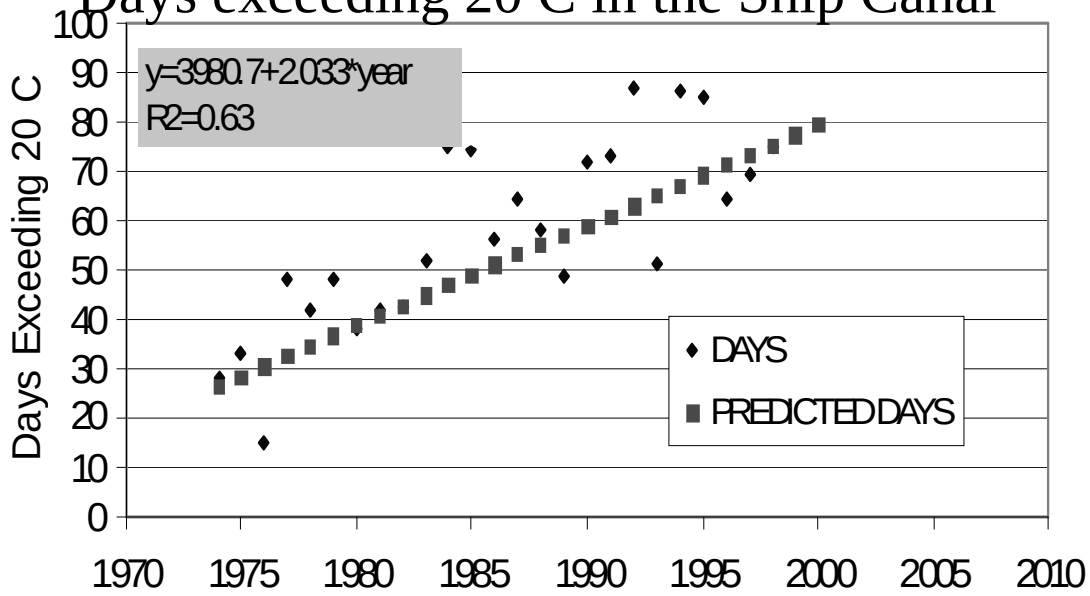
Hypotheses:

1) high water temperatures (and/or low dissolved oxygen) further upstream of the Locks are a barrier that adults will not swim through;

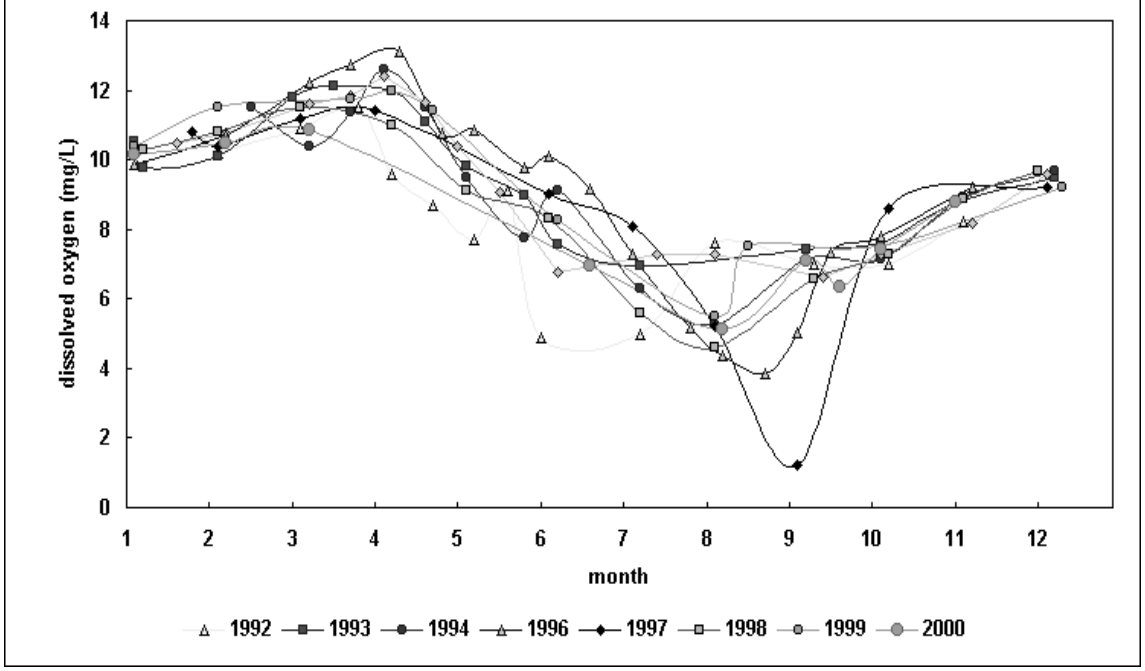
2) the area immediately upstream (within 1000 ft) of the Locks is a necessary cool water refuge where adults can safely hold until temperatures drop; and

3) what series of lock operations can improve the quality (dissolved oxygen, temperature, salinity) of the cool water refuge (and how do chinook respond to operational changes).

Days exceeding 20 C in the Ship Canal



Monthly DO Levels at the Fremont Cut 92-00



Adult Fish Passage

Increasing Water Temperature may be delaying adult migration

OR

Temperature And Low Dissolved Oxygen

OR

? ? ? ? ?

Adult Chinook Passage

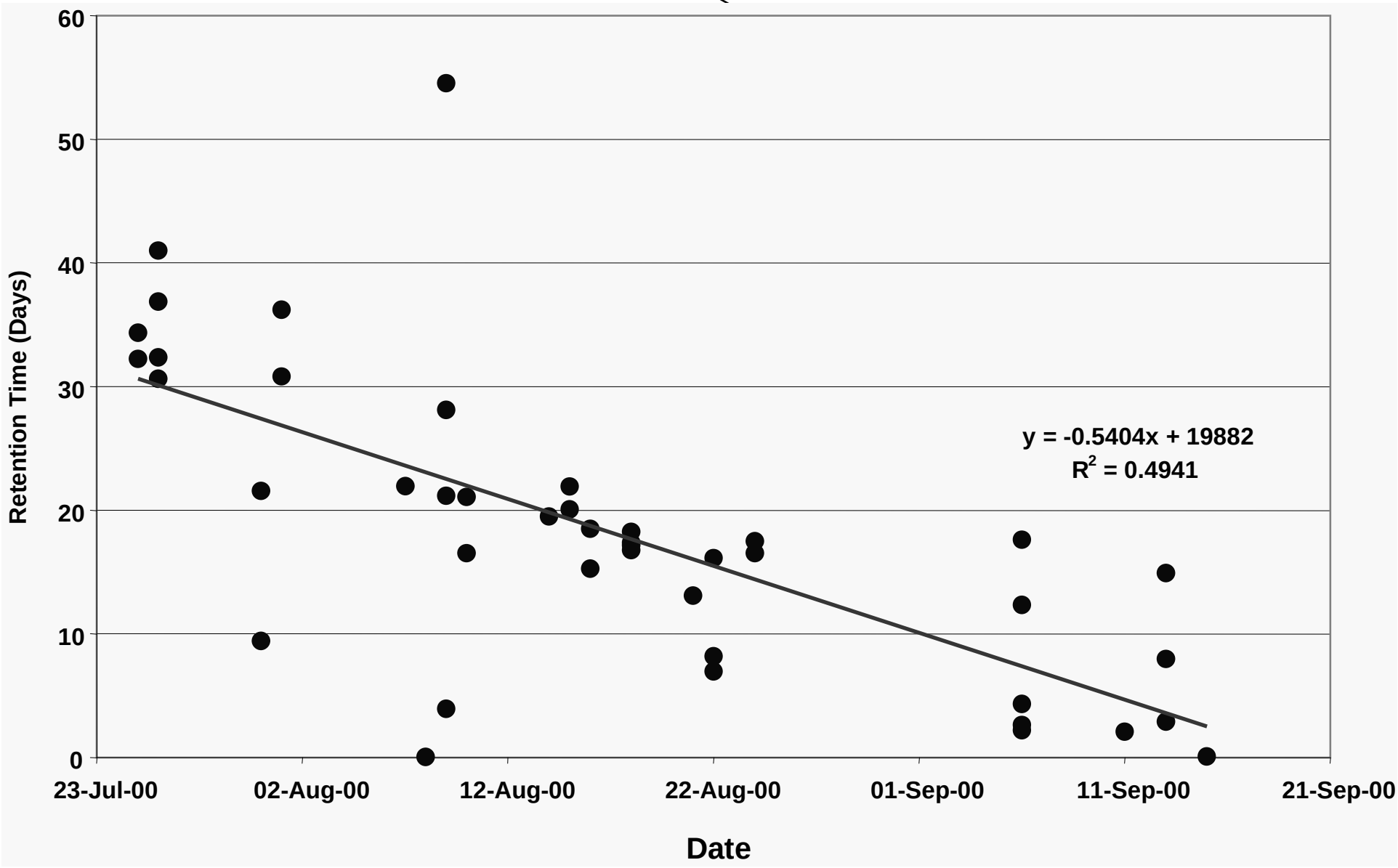
Experiment: A series of lock operations were developed and monitored to explore the second and third hypotheses. In 2000, adult chinook salmon behavior and water quality conditions were monitored during the operational testing.

Results:

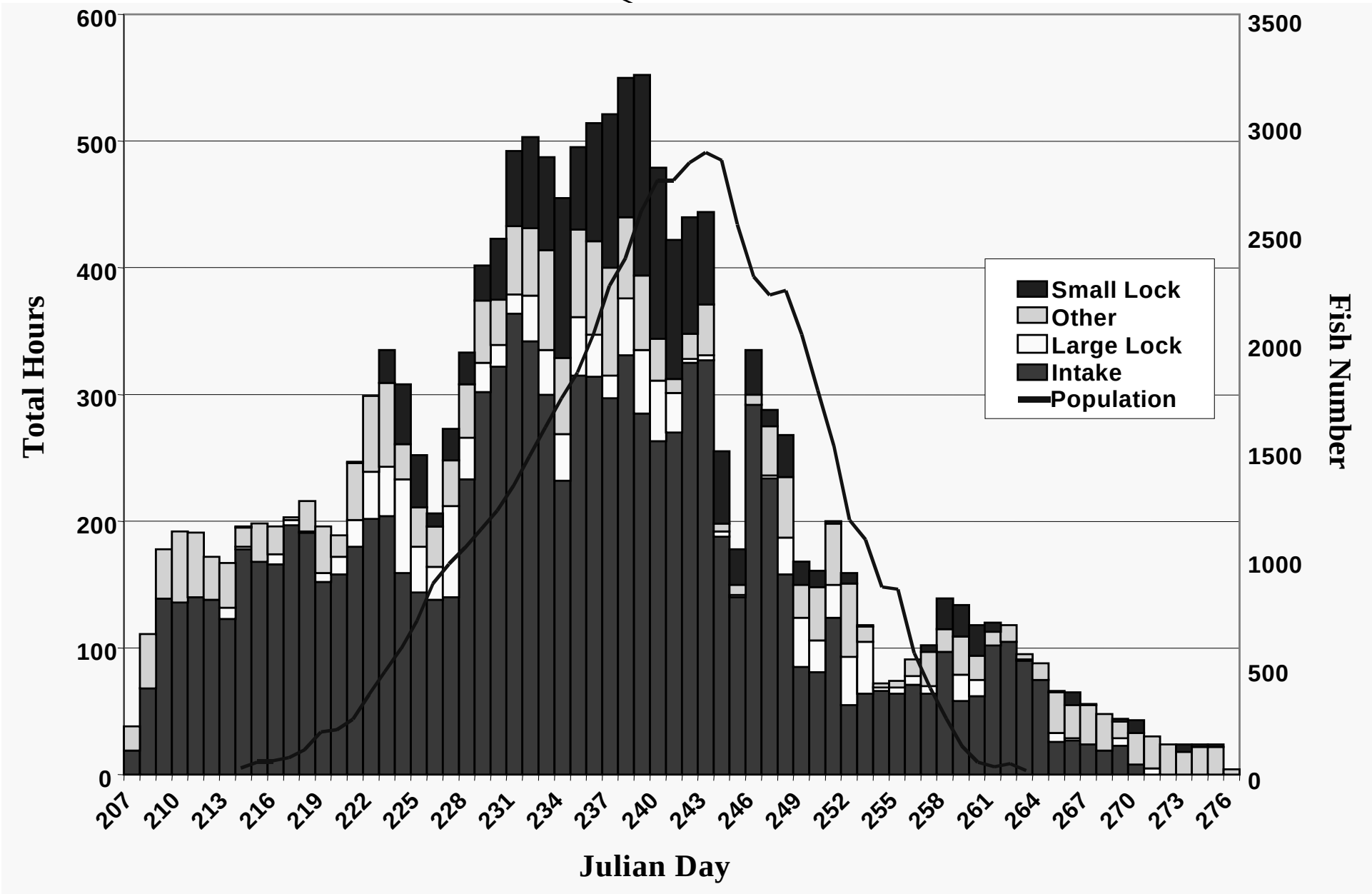
Initial analyses showed aggregate fish position:

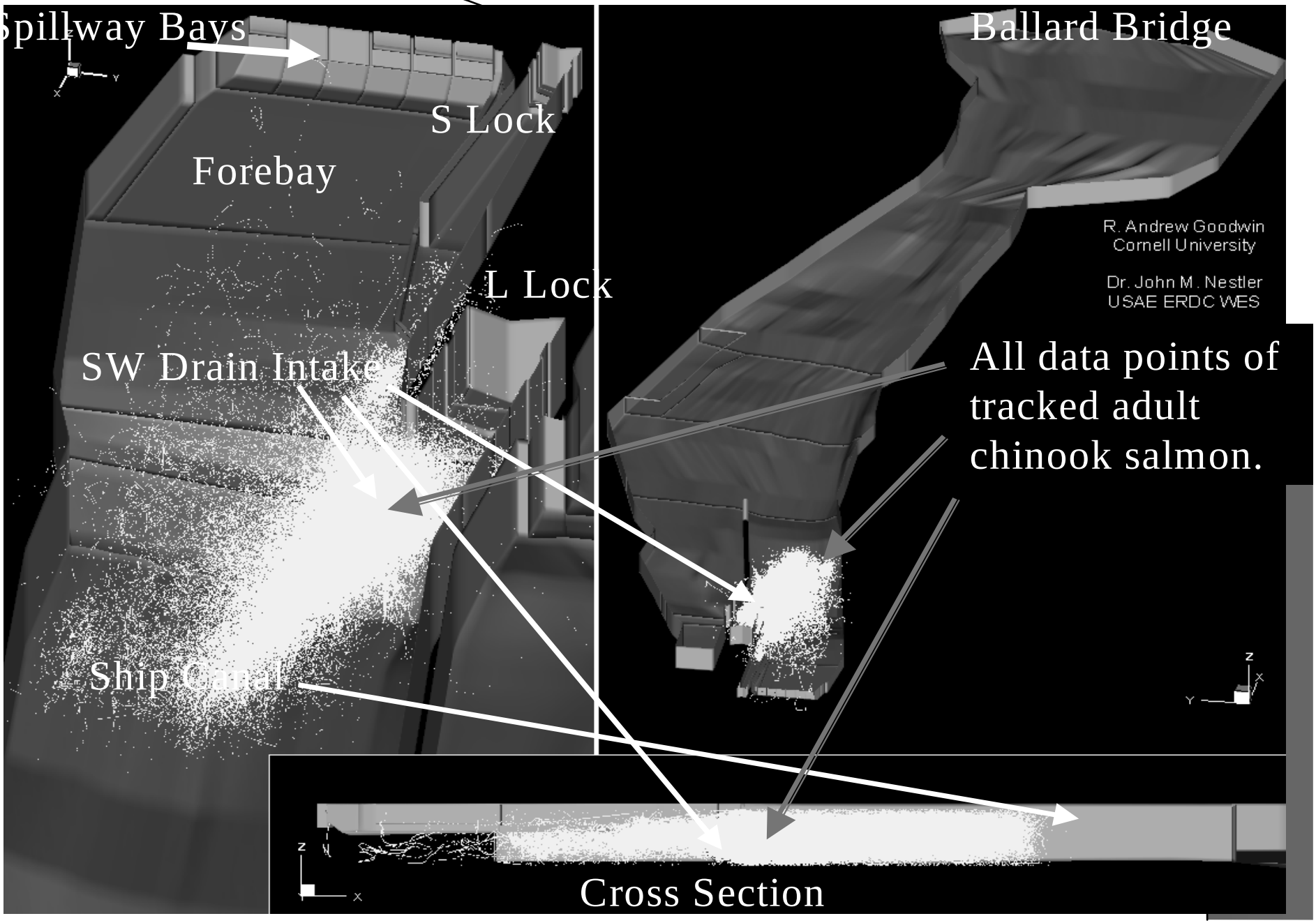
- **80% of all hours near the SW drain and lock entrance**
- **Mean fish depth was 7.0-7.4 m and varied little**
- **Mean depth of fish was found at**
  - **- salinity values of 0.5-1.0 ppt**
  - **- temperature of 20.5-21.5 C**
  - **- DO 7.5 mg/l at study start and 6.7 mg/l at end.**

Lock Residence Time vs. Entry Date

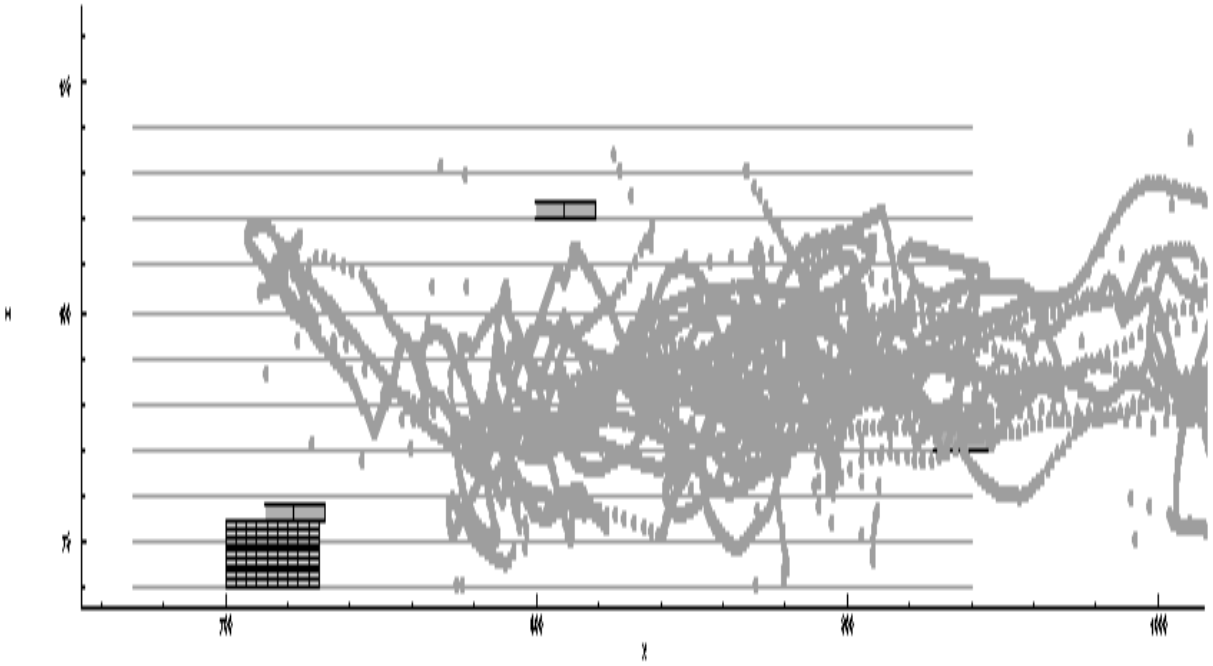


Area Residence Time & Estimated Population

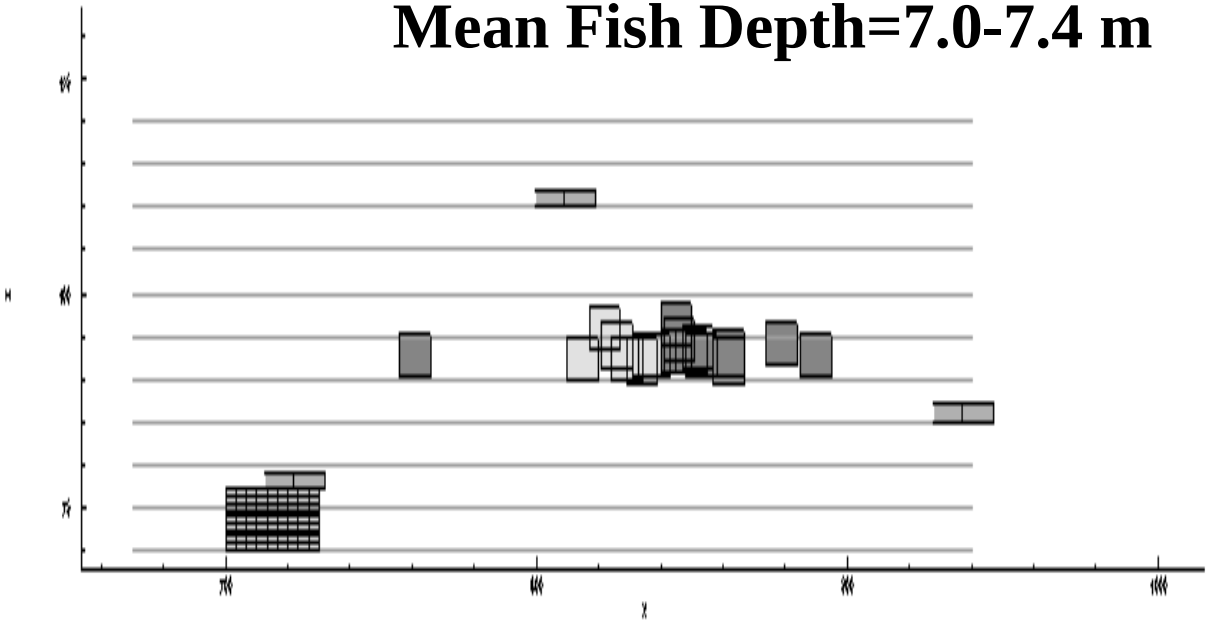



Spillway Bays
S Lock
Forebay
L Lock
SW Drain Intake
Ship Canal
Ballard Bridge
R. Andrew Goodwin
Cornell University
Dr. John M. Nestler
USAE ERDC WES
All data points of tracked adult chinook salmon.
Cross Section

Make-up of the Data Cloud Individual Vertical Fish Tracks



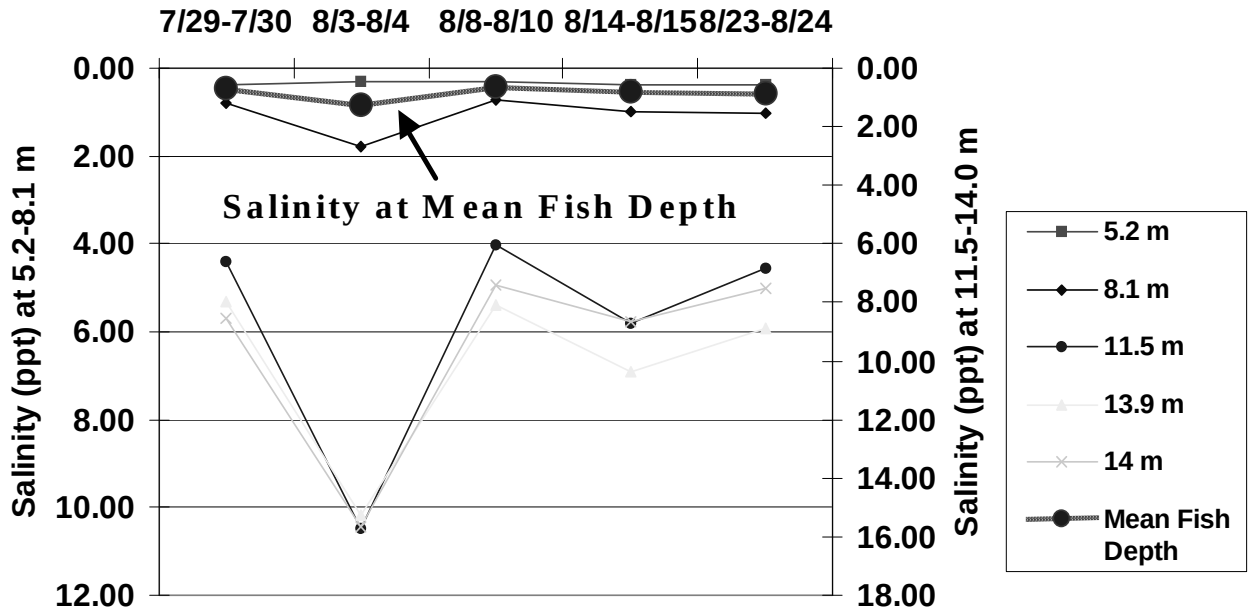
Mean Fish Depth=7.0-7.4 m



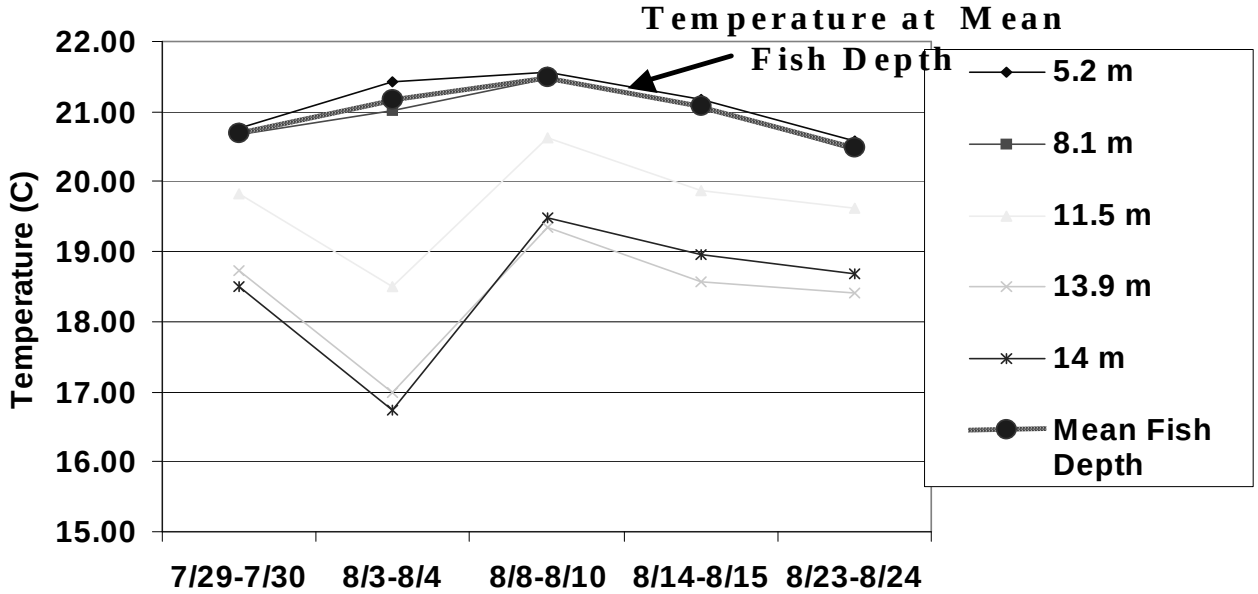
Mean position of all echoes

Mean position of echoes close proximity to saltwater drain

Vertical Fish Position vs. Salinity



Vertical Fish Position vs. Water Temperature



Coupled Ecological Model

Problem:

- **Unlike juvenile salmon studies to date, changes to Lock operations that might affect adult chinook could be tested using ecological modeling that should allow evaluation of adaptive actions without changes in locks structure or operation.**

Method:

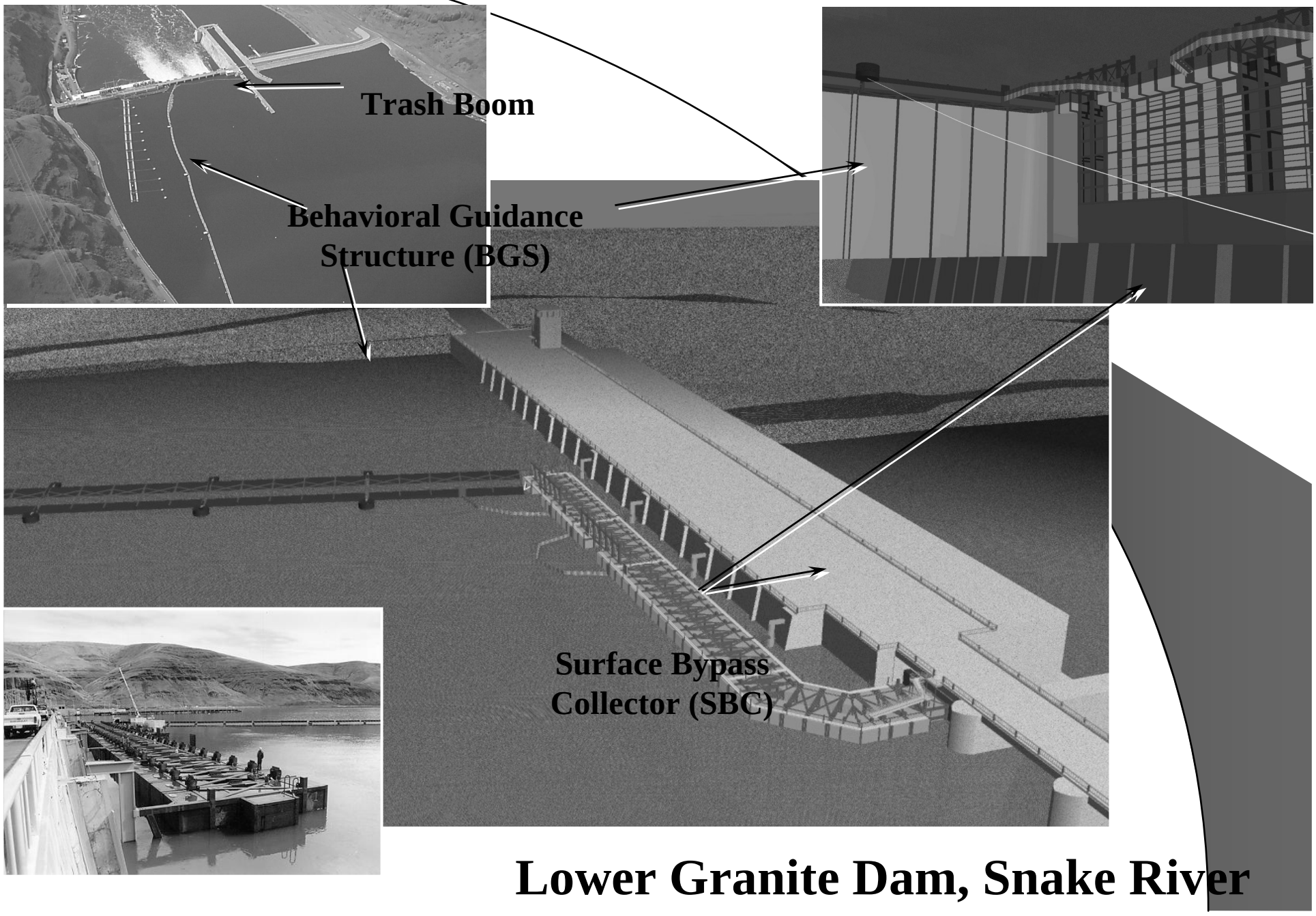
- **To evaluate the monitoring data a coupled ecological model linking a hydrodynamic *engineering model* (computational fluid dynamics (CFD) – flow and water quality) of the Ship Canal and a *biological model* (fish behavior - numerical fish surrogate -NFS) is being developed.**
- **This model can be used to further explore the monitoring data (fish behavior in response to environmental change), evaluate the hypotheses, and possibly to test and evaluate new scenarios of Lock operations or structural changes.**

Information Papers on Coupled Ecological Models

- **Nestler, J.M., R.A. Goodwin, and D.P. Loucks. In Press. Eulerian-Lagrangian coupling of engineering and biological models for ecosystem analysis. ASCE Journal of Water Resources Planning and Management**
- **Nestler, J.M. and R.A. Goodwin. In Review. Quantitatively relating juvenile salmon movement behavior to hydrodynamic cues in a hydropower dam forebay. Transactions of the American Fisheries Society.**
- **Nestler, J.M., R.A. Goodwin, T.M. Cole, D. Degan, and D. Dennerline. 2002. Simulating movement of blueback herring in a southern impoundment. Transactions of the American Fisheries Society 131:55-69.**
- **Information paper on Blueback Herring Model. http://www.wes.army.mil/el/emrrp/pdf/em02.pdf Powerpoint Presentation on Blueback Herring Fish Model. http://www.wes.army.mil/el/emrrp/nfs/pdfs/2Dfish.pdf**

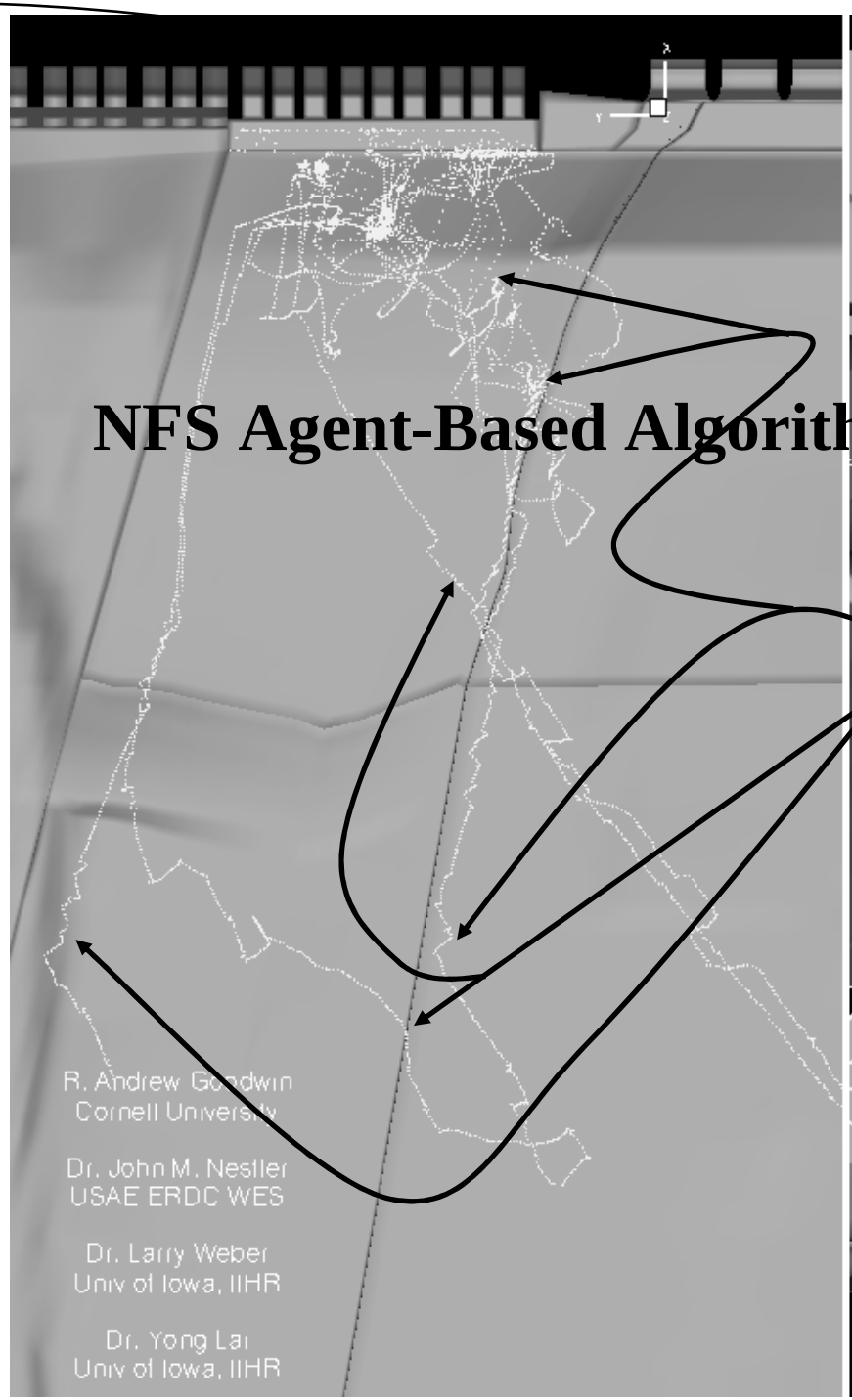
Lower Granite Dam
Coupled Ecological Model

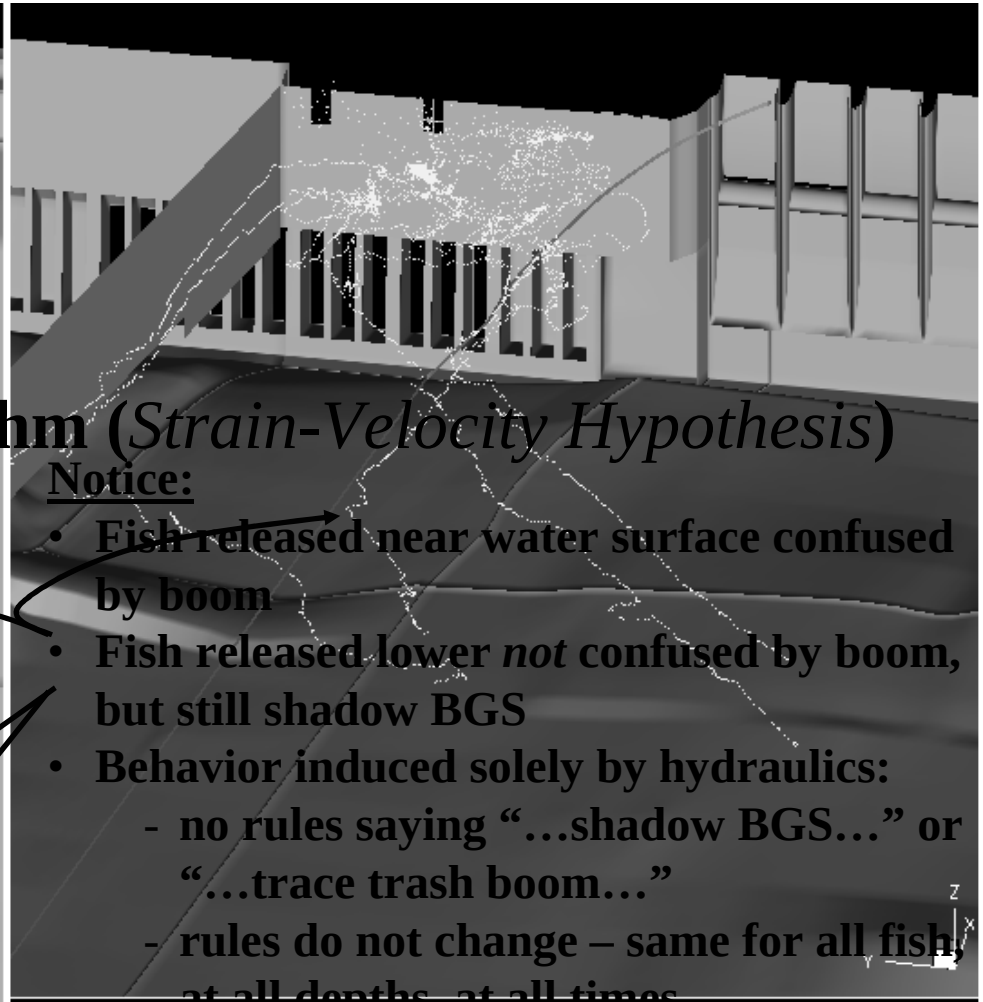
- **Coupled ecological models are a modeling form that links engineering models of water flow and quality with biological models (in this case fish behavior). A CEL has been developed and tested at Lower Granite Dam (LGD).**
- **A hypothesis for juvenile salmon for juvenile salmon migration was developed for LGD by integrating literature on fish behavior, sensory biology, fundamentals of fluid mechanics, and basic principles of river geomorphology.**
- **The hypothesis was tested using 3-D acoustic data, 3-D fluid dynamics modeling, and 3-D spatially explicit, time varying plug and play fish movement simulator (numerical fish surrogate).**
- **The simulator output explains 74% of the variation in migrant passage. This simulator accurately forecasts passage performance of different designs and operations of the dam. This same technology is being applied at the Locks.**

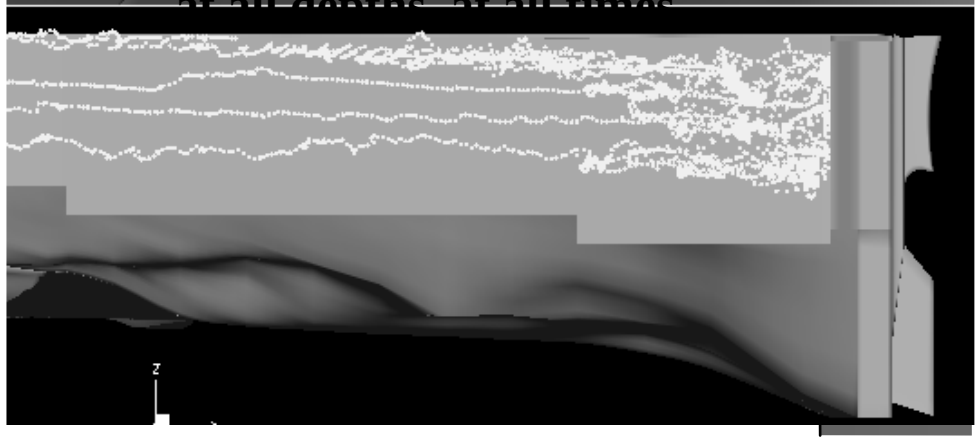


Lower Granite Dam, Snake River

NFS Agent-Based Algorithm (*Strain-Velocity Hypothesis*)

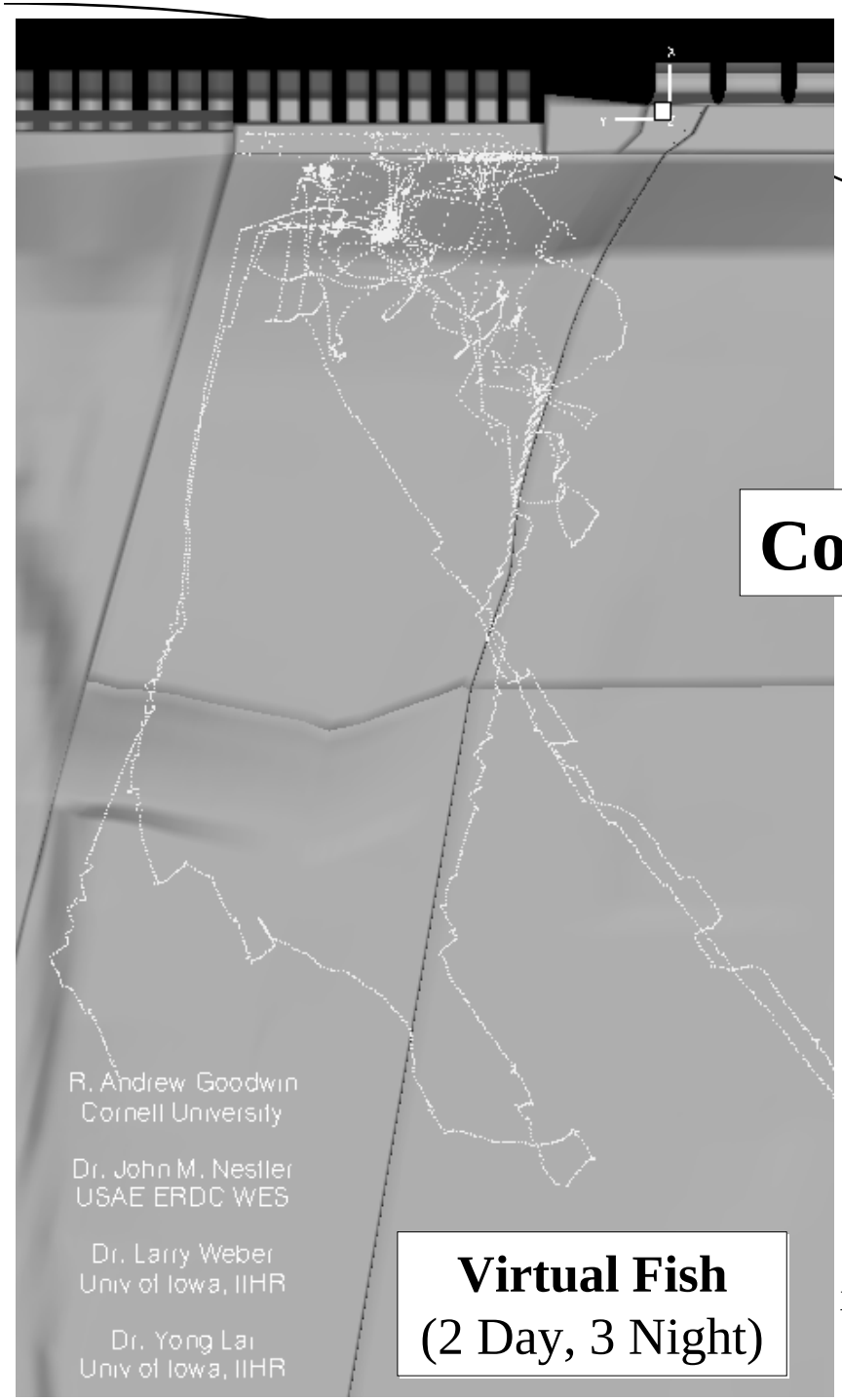






Notice:

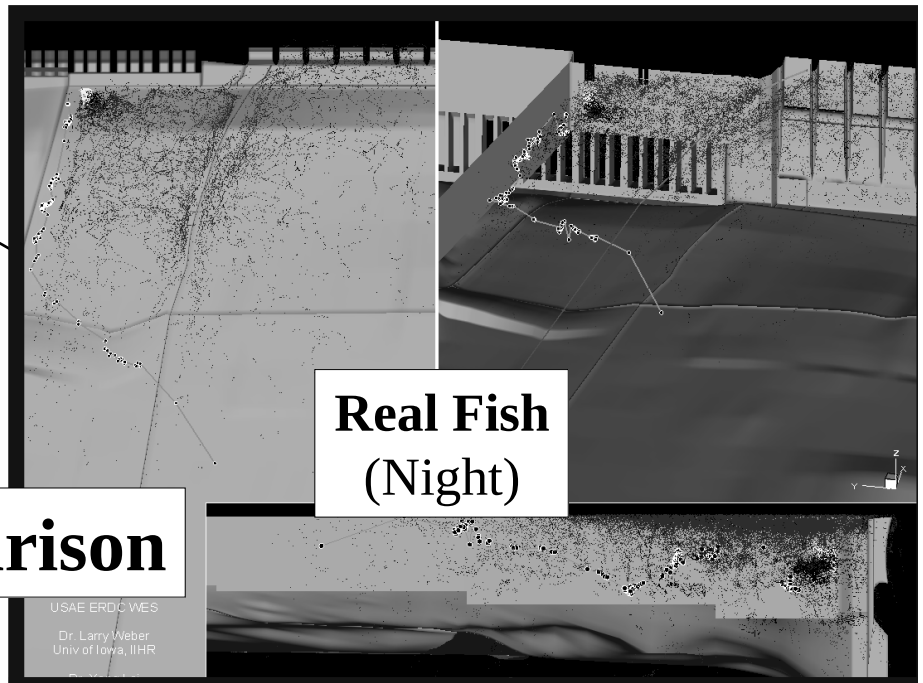
- **Fish released near water surface confused by boom**
- **Fish released lower *not* confused by boom, but still shadow BGS**
- **Behavior induced solely by hydraulics:**
  - **no rules saying "…shadow BGS…" or "…trace trash boom…"**
  - **rules do not change – same for all fish, at all depths, at all times**



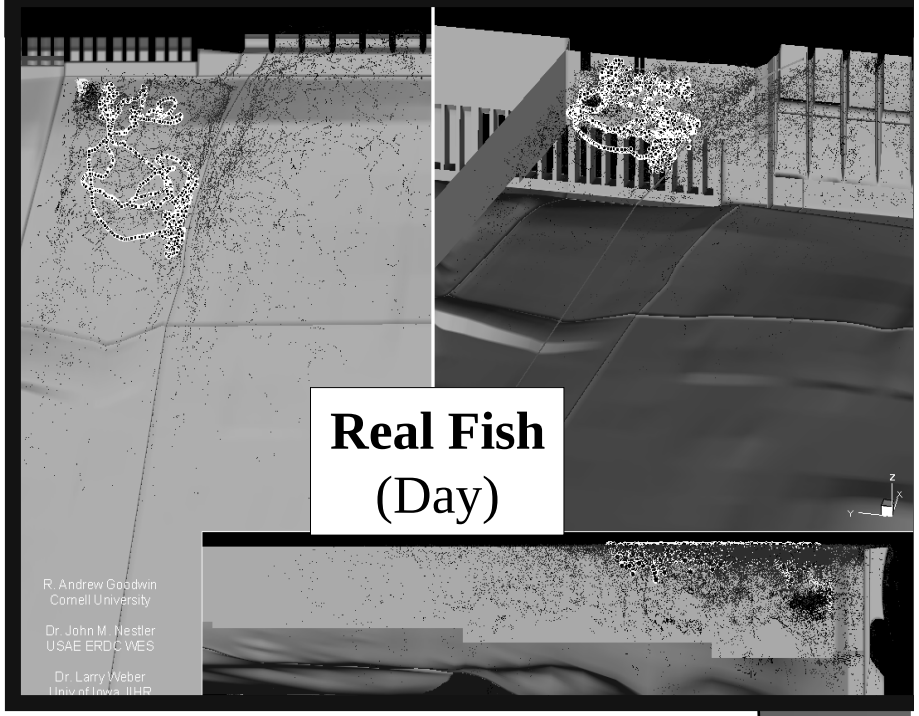
Virtual Fish
(2 Day, 3 Night)

Comparison

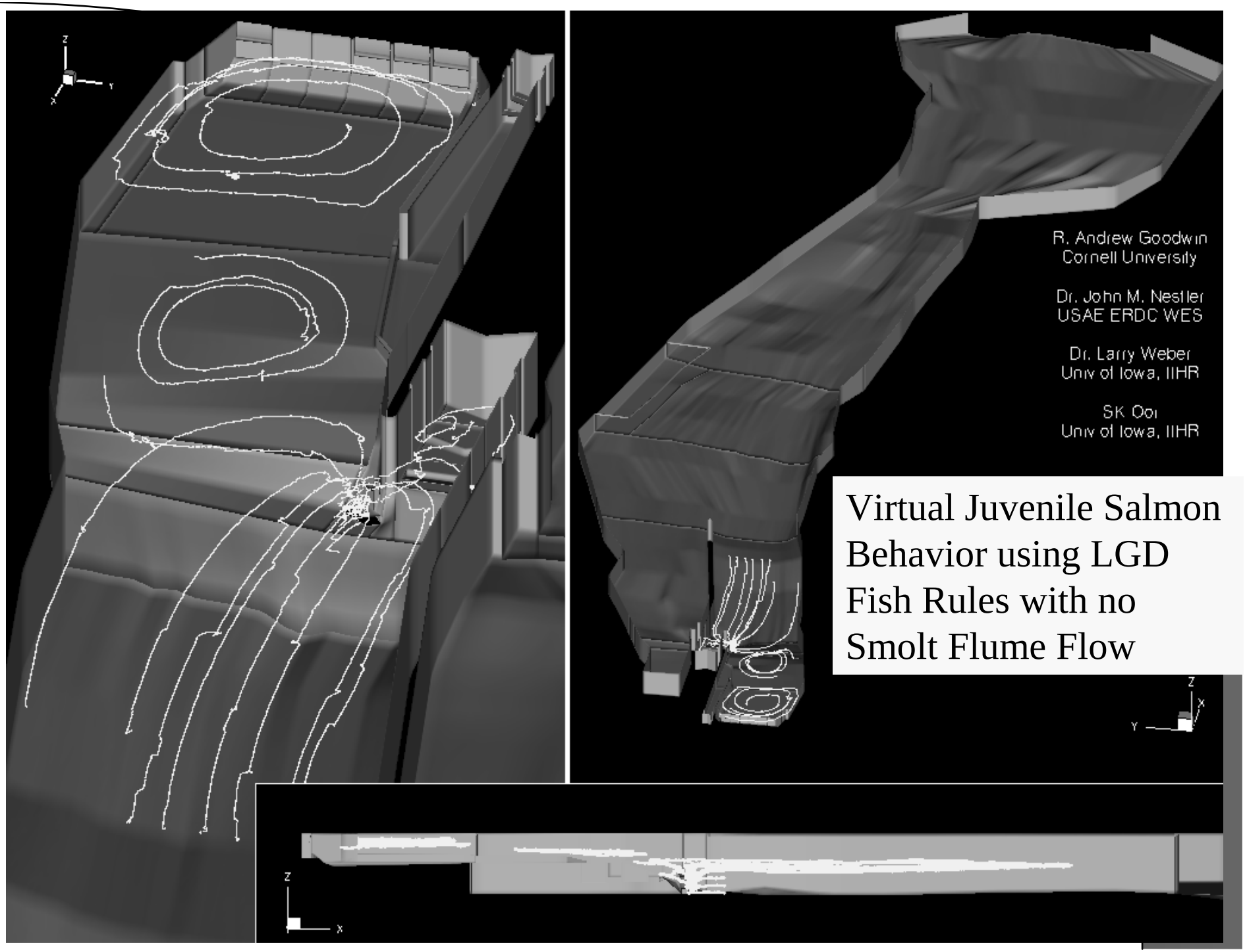
x : y : 2z



Real Fish
(Night)



Real Fish
(Day)


R. Andrew Goodwin
Cornell University
Dr. John M. Nestler
USAE ERDC WES
Dr. Larry Weber
Univ of Iowa, IIHR
SK Ooi
Univ of Iowa, IIHR
Virtual Juvenile Salmon Behavior using LGD Fish Rules with no Smolt Flume Flow

Input

Flow Data
- {x, y, z, flow and WQ data}
- CFD / instrumentation
- time-variant / steady-state

Input

Tracking Data
- {x, y, z, fish ID, time}

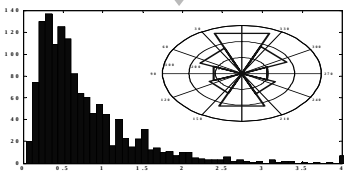
Vector Generation & Integration
(NFS-VGI)

Statistical & Graphical Analyses
(NFS-SGA)

Input

Knowledge & Experience
- theory of fish mechanosensory systems
- theory of biological movement (game theory)
- previous simulation modeling:
  - 3-D sub-meter movements / seconds
  - 2-D distributions over kilometers / months
- observations
- hypotheses

-of-Magnitude
tion



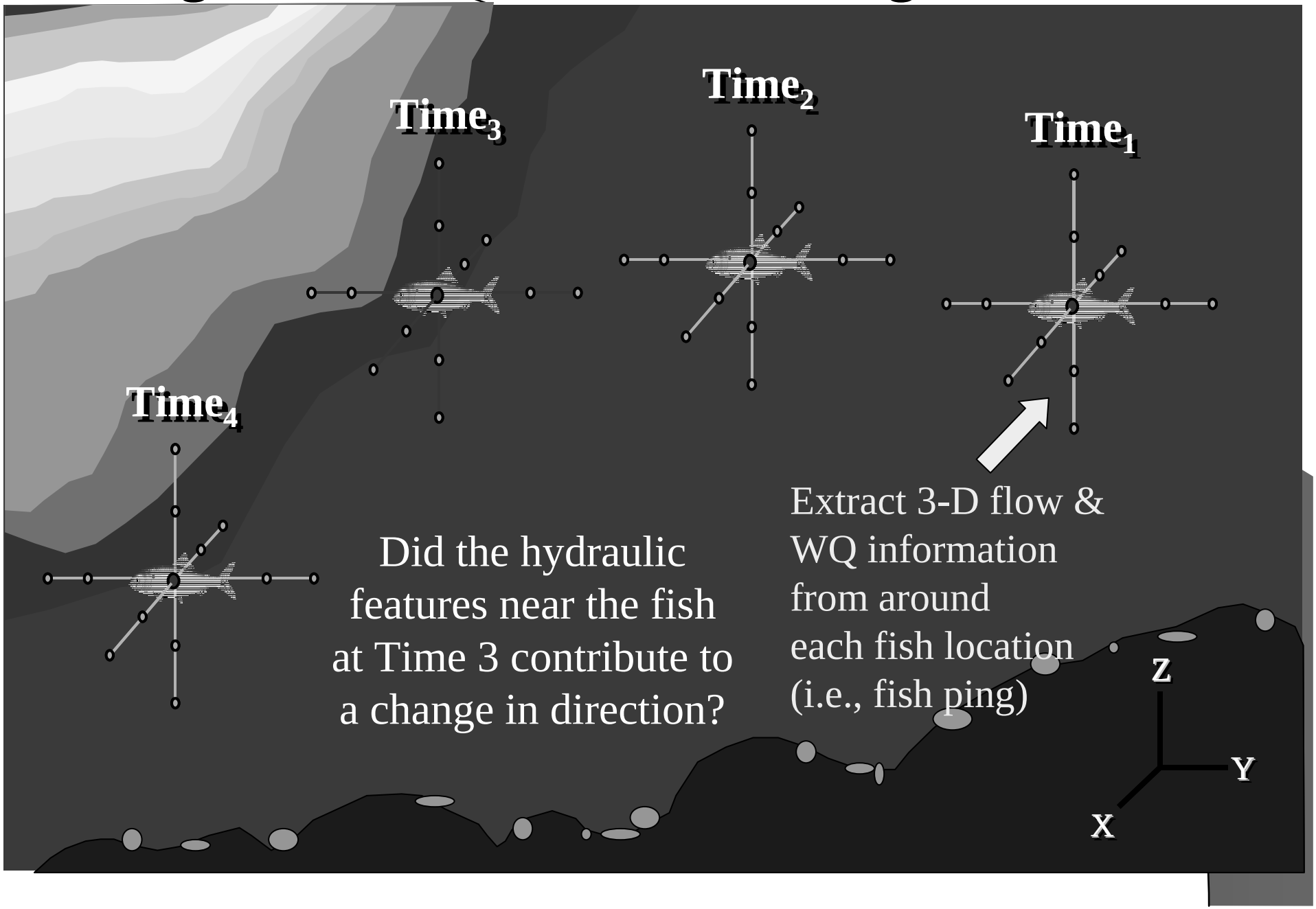
Simulate Virtual Fish
(NFS-SIM)

Virtual Tracking Data
- {x, y, z, fish ID, time}

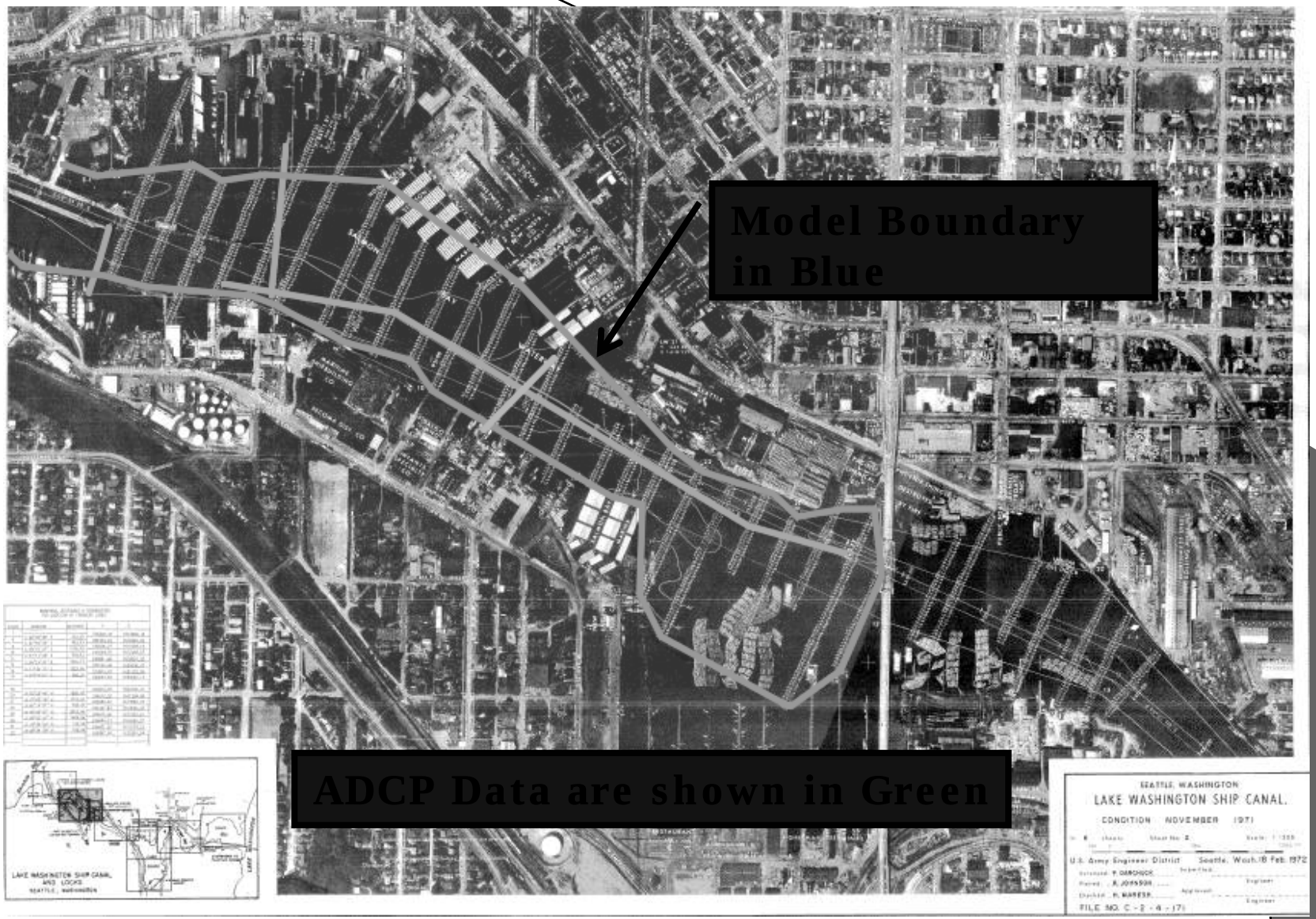
Statistical & Graphical Analyses
(NFS-SGA)

w

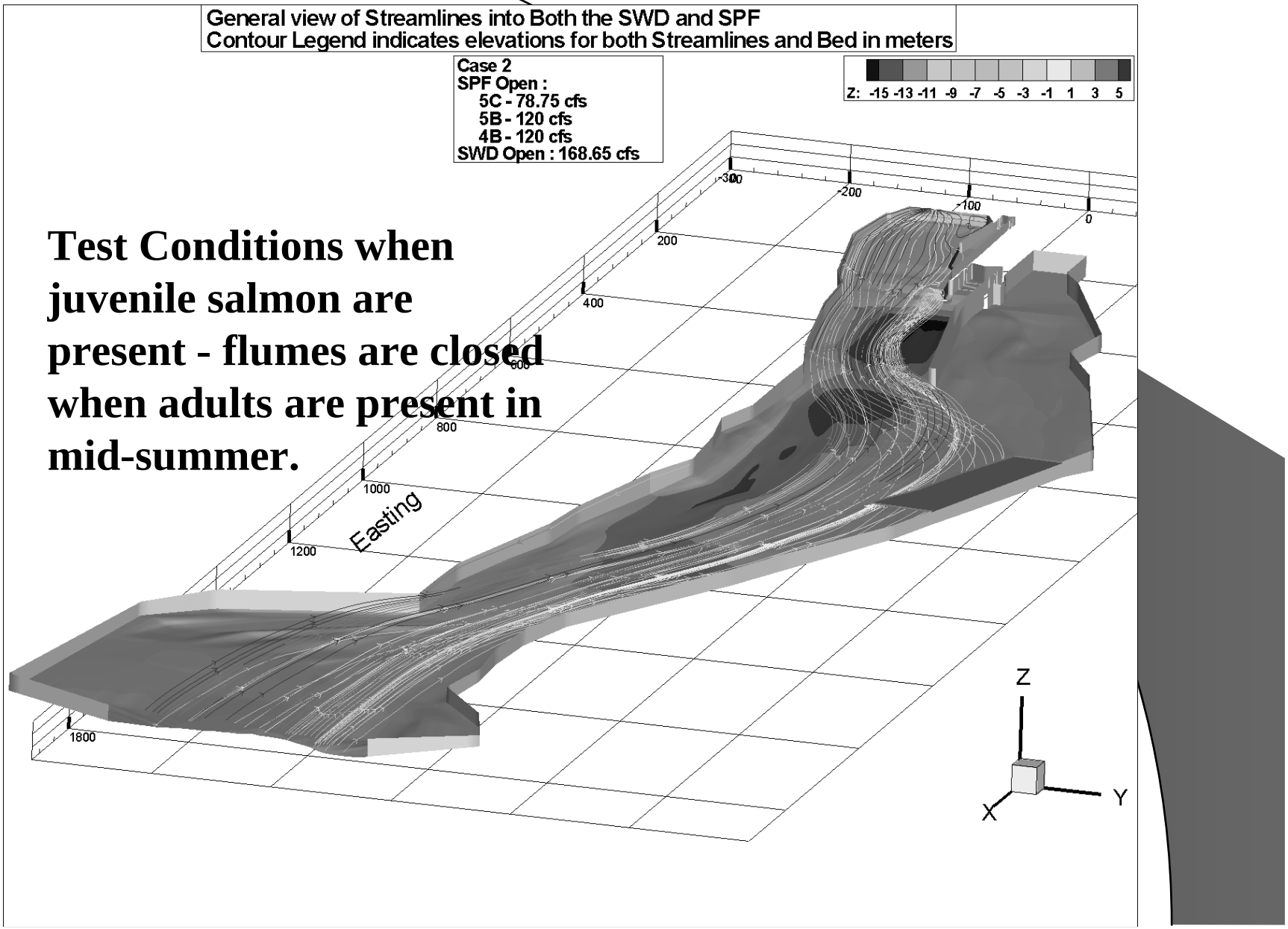
Integration of CFD and Tracking Information



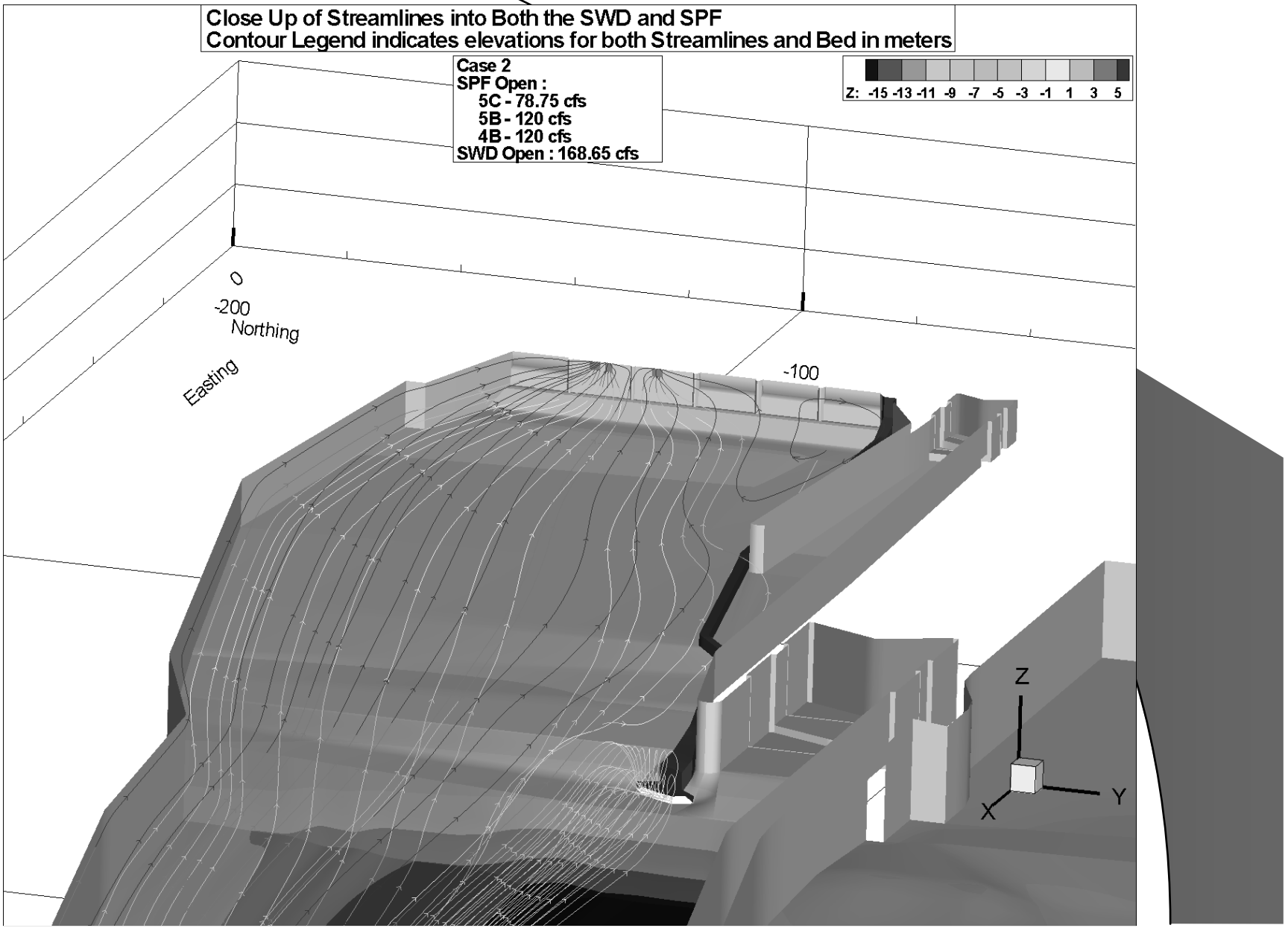
Locks CFD Model Boundary and Field Data



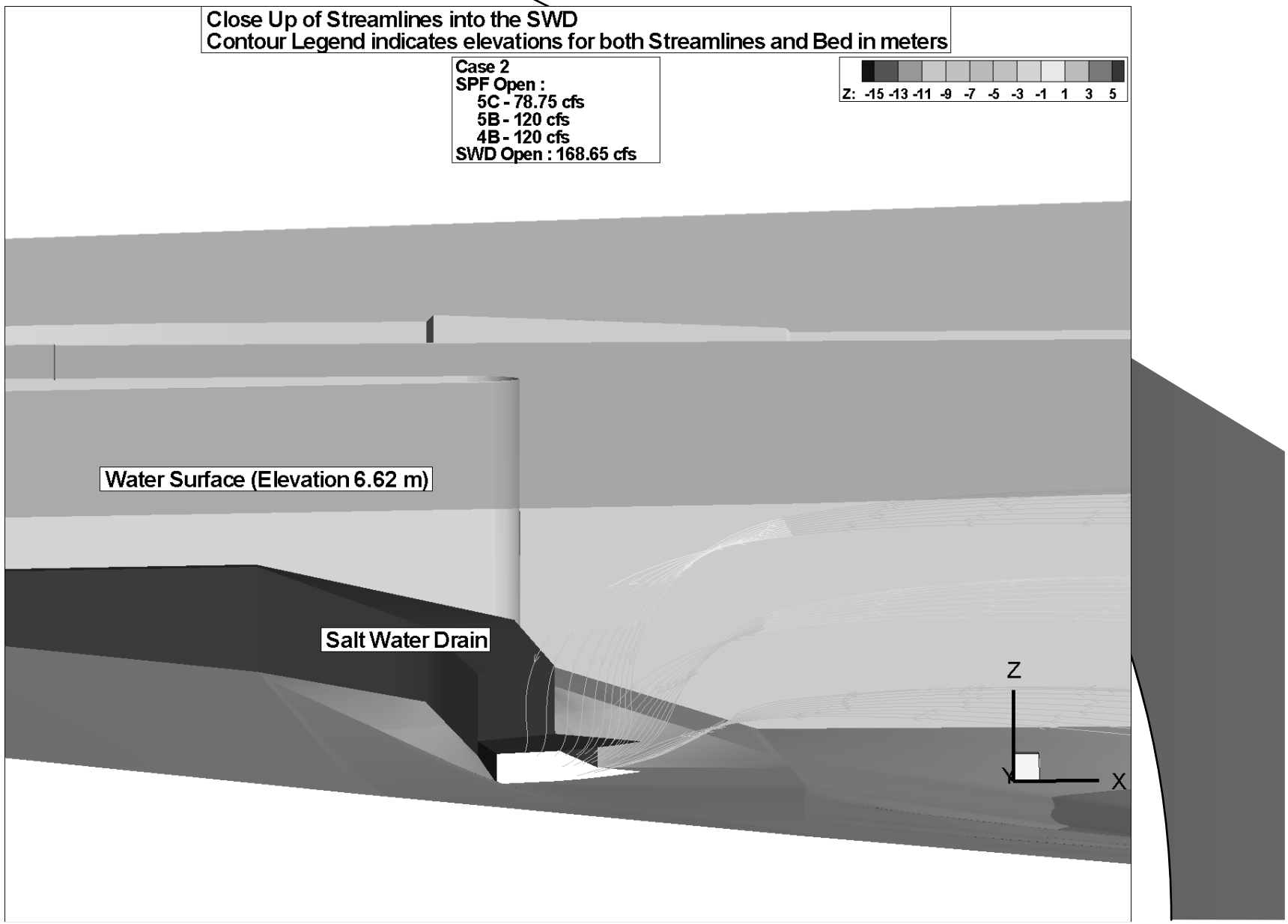
Example CFD Output – General View Water Velocity with Smolt Flumes Open

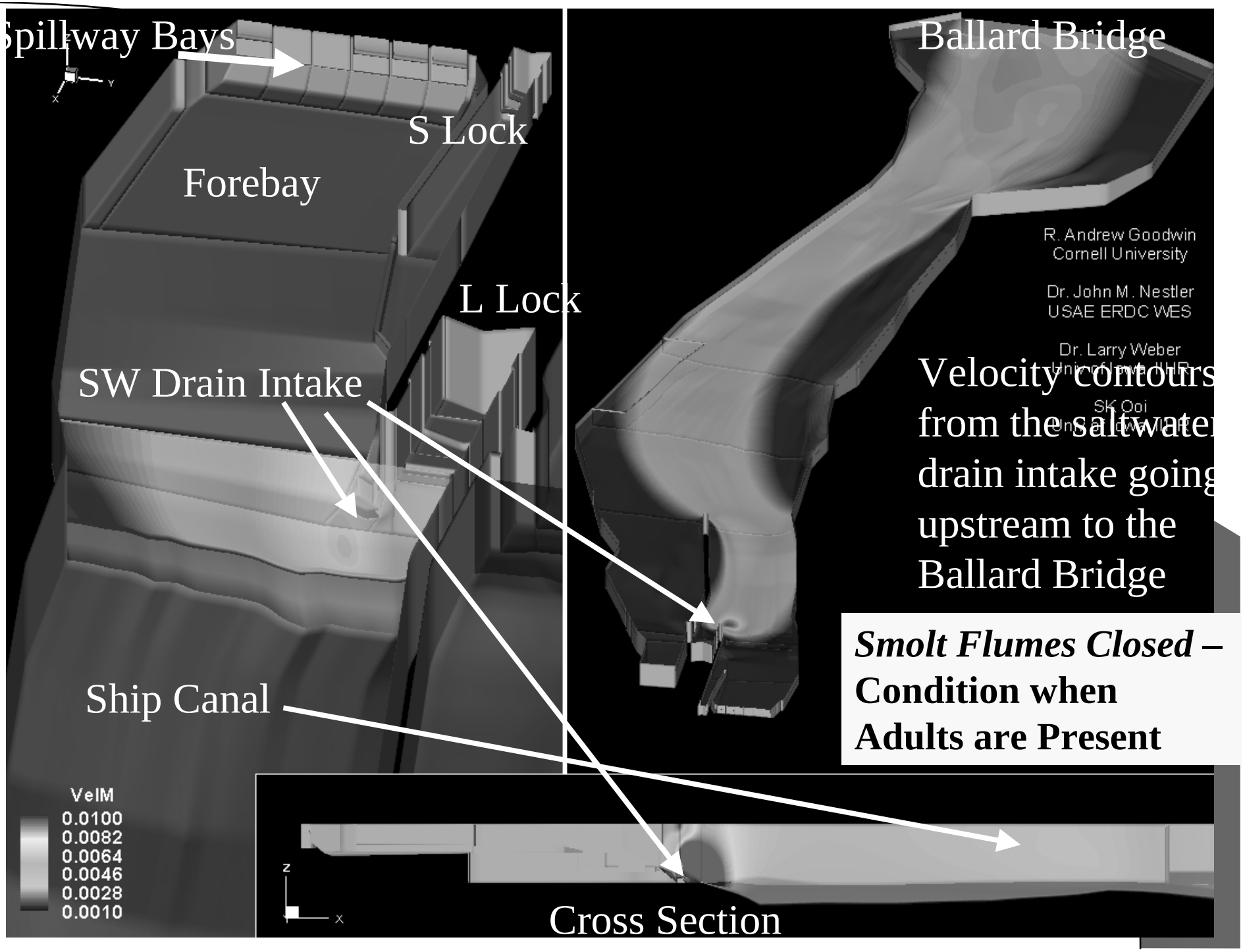


Example CFD – Close Up of Streamlines at Lock with Smolt Flumes Open

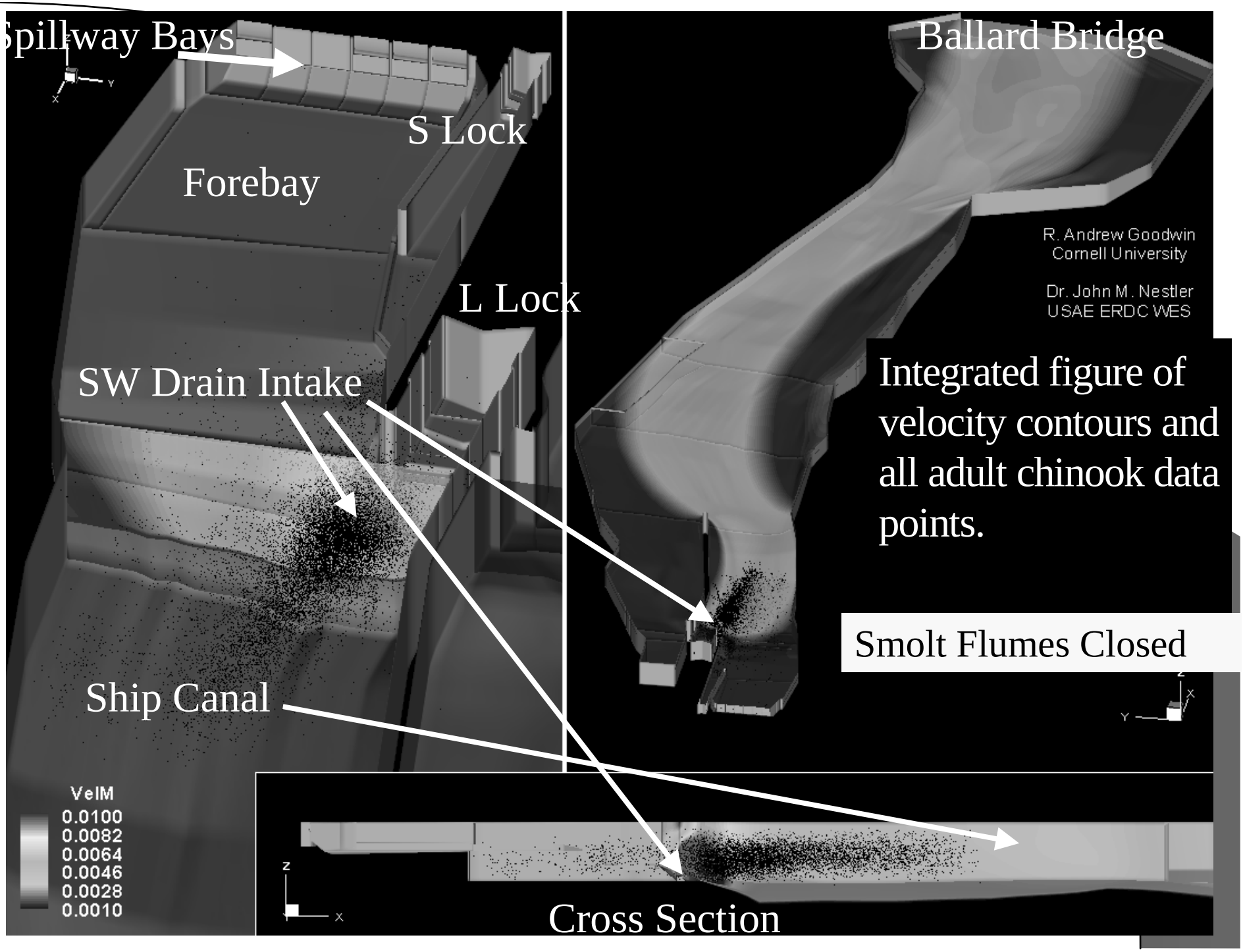


Example CFD – Close up at Salt Water Drain with Smolt Flumes Open





***Smolt Flumes Closed* – Condition when Adults are Present**


Spillway Bays
S Lock
Forebay
L Lock
SW Drain Intake
Ship Canal
Ballard Bridge
R. Andrew Goodwin
Cornell University
Dr. John M. Nestler
USAE ERDC WES
Integrated figure of velocity contours and all adult chinook data points.
Smolt Flumes Closed
VelM
0.0100
0.0082
0.0064
0.0046
0.0028
0.0010
Cross Section

Conclusions

- **We used a pilot technology to accurately track adult chinook in a very small localized area. This same technology is being applied throughout the Columbia River.**
- **Adult studies have moved beyond actual physical testing and monitoring of results and are attempting to employ ecological modeling as an adaptive evaluation tool.**
- **Locks model work in 2004 will include statistically relating the behavior of adult salmon in the Chittenden Locks to patterns in flow, temperature, and salinity (DO might be added to the model).**
- **We expect the model can then be used to quantitatively evaluate each possible operational scenario (night lockings) or design alternative (move the SW Drain) considered for the Locks by using virtual fish.**
- **Beyond 2004, future work will include addition of juvenile salmon monitoring behavior to the coupled ecological model-allowing scenario testing of both adult and juvenile salmon under different structural and operational conditions.**
- **The model grid can also be expanded to allow modeling of saltwater intrusion up to the University Bridge.**